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1. 研究題目

NICEBOT―安全で人にやさしいロボットの開発

2. 研究目的

本研究は、関節にクラッチを使用した特殊なアクチュエータを組み込むことにより、安全性の高いロボットアームを開発することを目的としている。本研究で使用するアクチュエータの特徴として、人や物との衝突の際に衝撃を和らげることができること、そして動作の直接教示(ティーチング)を容易に行えることが挙げられる。

3．研究内容及び成果

Ａ．ハードウェア開発

A-1. モジュール設計：We implemented two generations of the improved actuator module. We performed various tests and confirmed that the actuator modules work. Especially the latest version of the actuator module makes it is easy to assemble robots with it. The actuator module is also stronger than before without a significant increase in size, by using a low ratio speed reducer after the clutch. These modules will be used for the next generation of Nicebot, as described below.

A-2. 新型の手首：We have implemented the new wrist and attached it to the robot, please see Figure 1. The wrist performs satisfactorily.

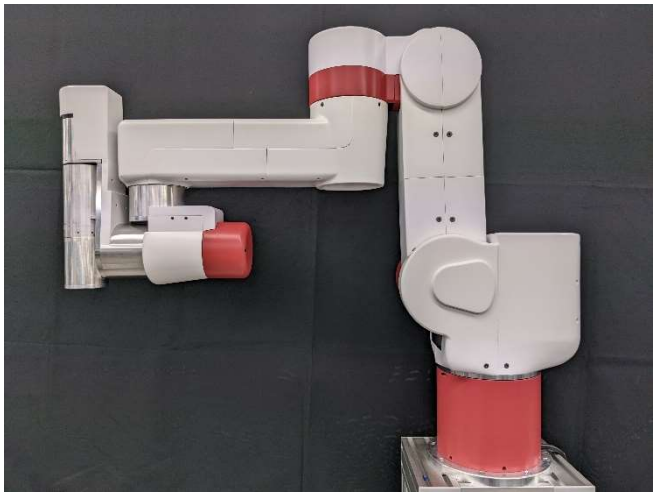


Figure 1: Painted robot with new wrist

Ｂ．ソフトウェア開発

B-1. 力制御アルゴリズムの実装：We have implemented the new algorithm and confirmed that the robot can follow unknown surfaces and apply constant force to the surface. We confirmed good results for various surfaces.

B-2. 安全性の向上：We have implemented the new safety algorithm for all movements. We could confirm that the robot applies forces of less than 220N even at the maximum speed of the robot.

B-3. 基本的なユーザー・インタフェースを提供するためのソフトウェア設計：We have implemented a simple GUI which makes it easy to setup the robot for various tasks. It is also possible to setup the robot for slightly complex tasks, like pick and place. However, we still need to further improve this GUI to make it easier to setup the robot for even more complex tasks.

In addition, we exhibited the robot with the improved hardware and software in the Schaeffler booth at IREX in March 2022. We also created a video of the improved robot, see Figure 2.

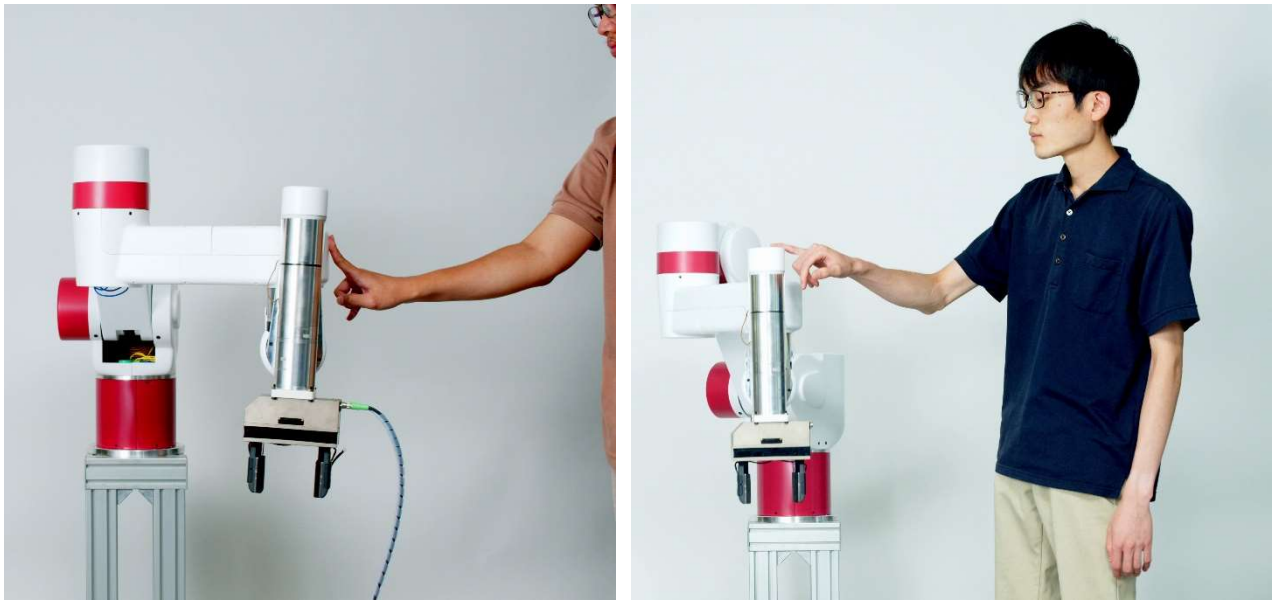


Figure 2.
Left: Safety Demo. It is possible to stop the robot with one finger.
Right: Direct Teaching Demo. It is possible to move the robot with one finger and teach it a trajectory.

4. 今後の研究の見通し

① Research Plan: Implement the next version of Nicebot without passive gravity compensation

The passive gravity compensation, which was previously used, introduces constraints on the shape of the robot and necessitates gaps in the robot's cover. Therefore, in this year we will implement a robot without passive gravity compensation, and instead use the actuator modules that were implemented previously. They maintain a certain torque limit even without power. During direct teaching and other operations, the weight of the robot will be actively compensated by controlling the clutches.

② Research Contents:

- Design and manufacture of Nicebot without passive gravity compensation mechanisms
- Control of Nicebot without passive gravity compensation

③ Research Methods:

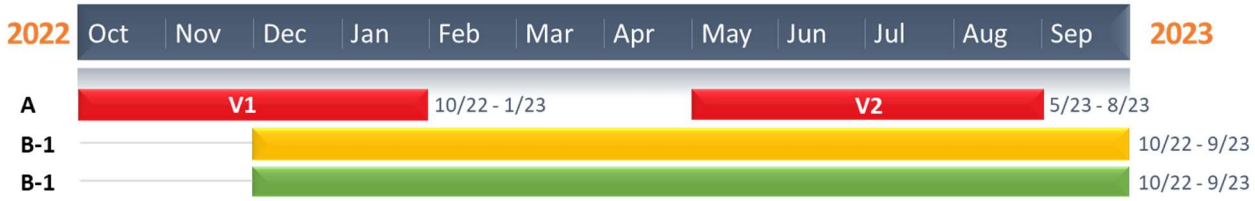
A. Hardware Development

As the whole weight of the robot will be supported by the motors, the clutches in series with the motors would need to be much stronger. We will use dual reduction gears in each actuator: a large reduction ratio between the motor and the clutch, and low reduction ratio after the clutch. As the clutches are not directly connected to the output anymore, they can be smaller dimensioned. Furthermore, the clutches will be modified to maintain a certain torque limit even without power.

B. Software Development

B-1. Safety: With passive gravity compensation, the clutches can completely decouple in case of impact. Without passive gravity compensation, they need to stay coupled to an extent so that the arm does not fall down due to gravity. We will implement a new safety algorithm that takes these and under effects in consideration.

B-2. Direct teaching: The clutches need to provide the torque to lift up the robot arm (instead of the passive gravity compensation), so that the robot arm is easy to move during direct teaching. We will implement the control algorithm to correctly set the clutches at each time step. The clutch temperature also needs to be taken into consideration, to produce the correct output torque.



5. 助成研究による主な発表論文，著書名

Muhammad Arifin, Yuta Kage, Yuchen Yang, Alexander Schmitz, Shigeki Sugano (submitted) *Active Gravity Compensation to Various Payloads using Series Clutch Actuators for Direct-Teaching Applications*. IEEE Transactions on Robotics (T-RO)

Planned for 2023: *NICEBOT - A safe and human-friendly robot*. Science Robotics. It should be an overview paper of all the functions of Nicebot.